

Quantitative Comparison of Viscous Hydro with Data

What is needed to make progress: the STAR-flavored view

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BERKELEY LAB

1) Introduction

2) Recent results:

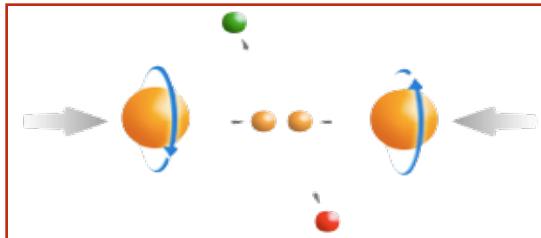
- Initial conditions and R_{AA}
- Centrality dependence v_1, v_2
- Search for the LPV

...

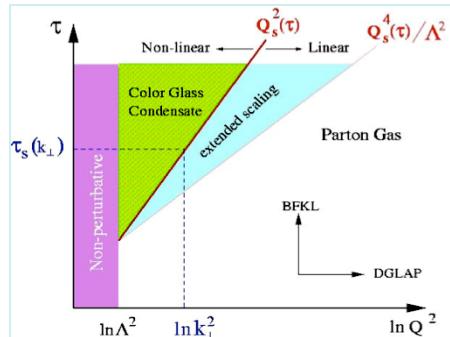
3) RHIC beam energy scan

4) Summary

STAR Physics Focus

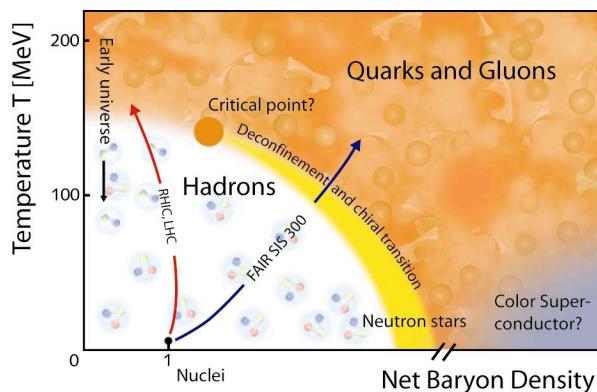


Polarized $p+p$ program
 - Study *proton intrinsic properties*



Forward program

- Study low-x properties, search for **CGC**
- Study elastic (inelastic) processes ($p+p \rightarrow p+p$)
- Investigate **gluonic exchanges**



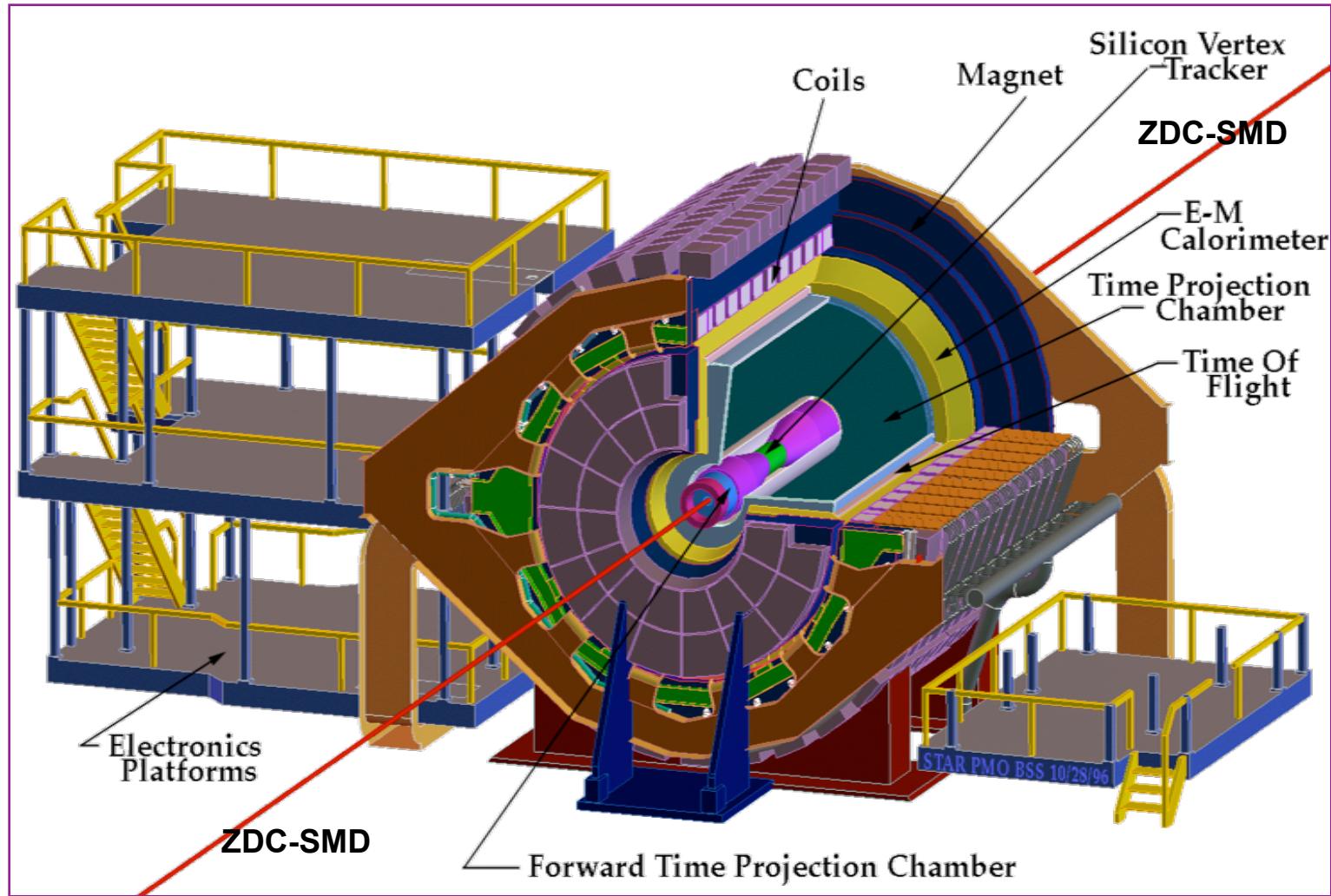
1) At 200 GeV top energy

- Study **medium properties, EoS**
- pQCD in hot and dense medium

2) RHIC beam energy scan

- Search for the **QCD critical point**
- Chiral symmetry restoration

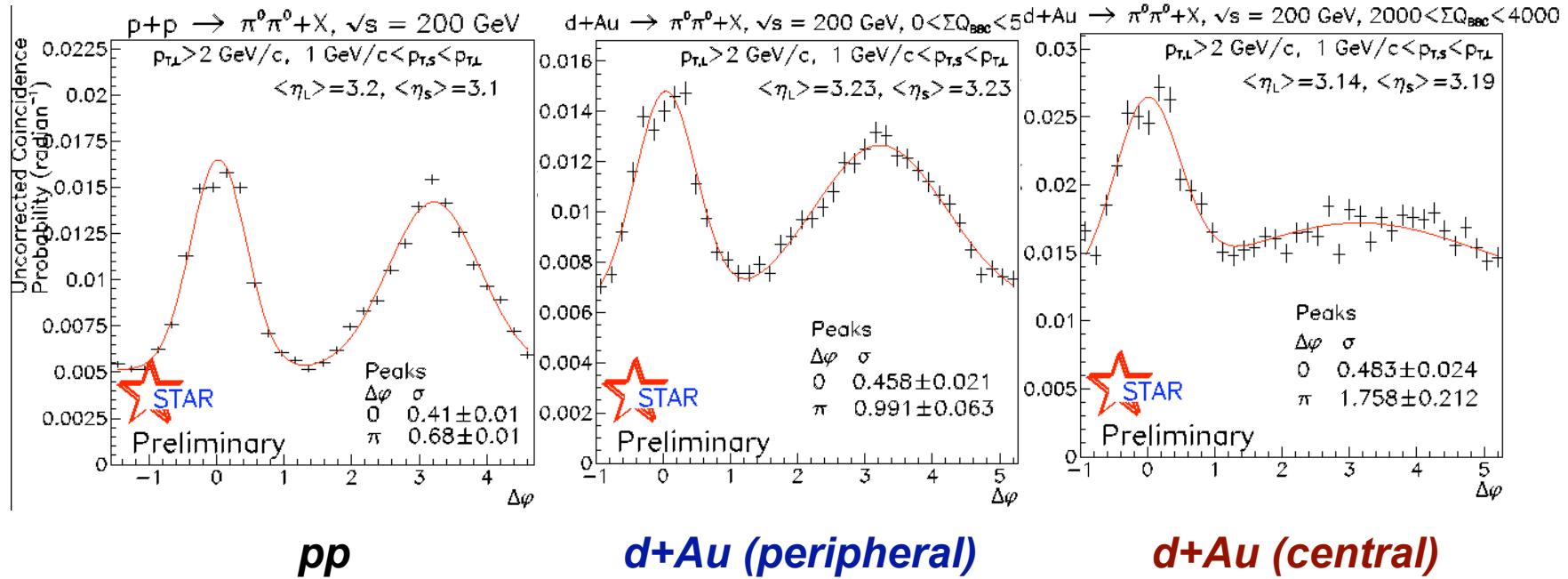
STAR Detectors (large acceptance)



Large rapidity gap: $v_2\{\text{FTPC}\}$, $v_2\{\text{ZDC-SMD}\}$

Initial Conditions and Nuclear Modification Factor R_{AA}

200 GeV $p+p$ and $d + Au$ Collisions Run8, STAR Preliminary

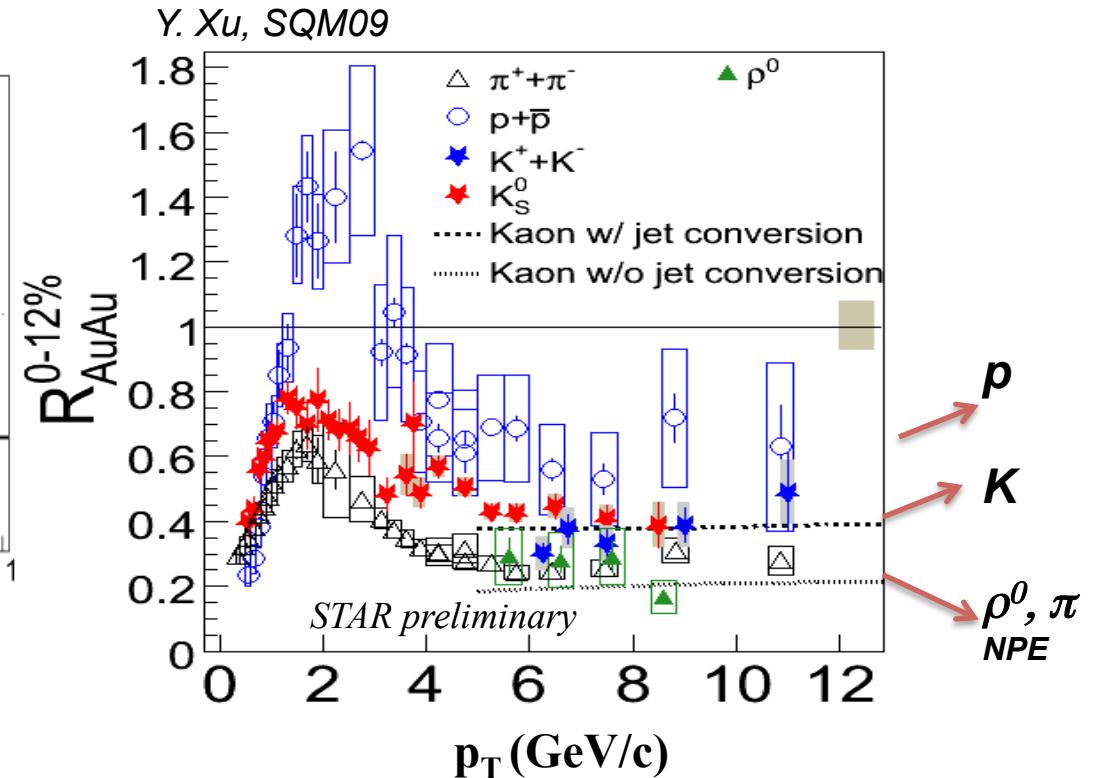
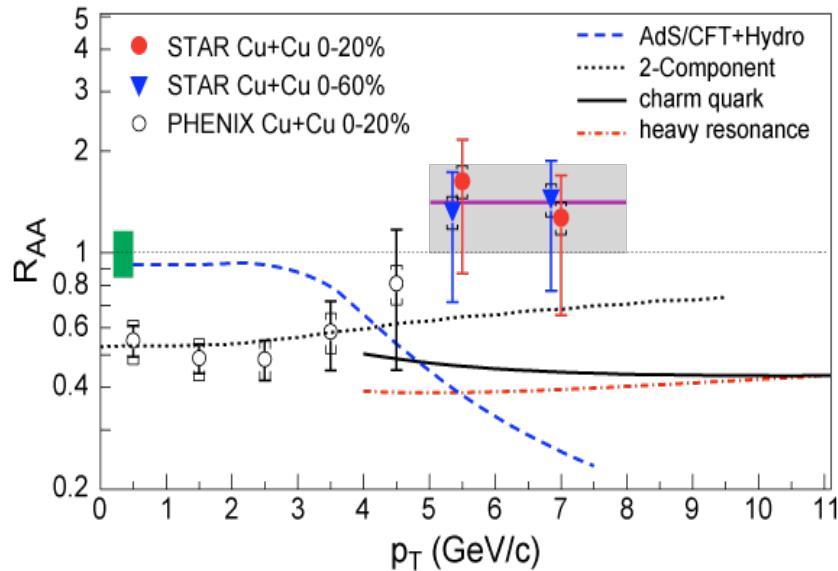


De-correlation observed away side.

See talk by A. Ogawa

Nuclear Modification Factor R_{AA}

STAR: PRC, 0904.0439



- 1) Flavor effect?: $R_{AA}(\pi) \sim R_{AA}(\rho^0) < R_{AA}(\phi) < R_{AA}(J/\psi)$
- 2) Mass effect?: $R_{AA}(\pi) < R_{AA}(K) \sim R_{AA}(p)$
- 3) Color effect???

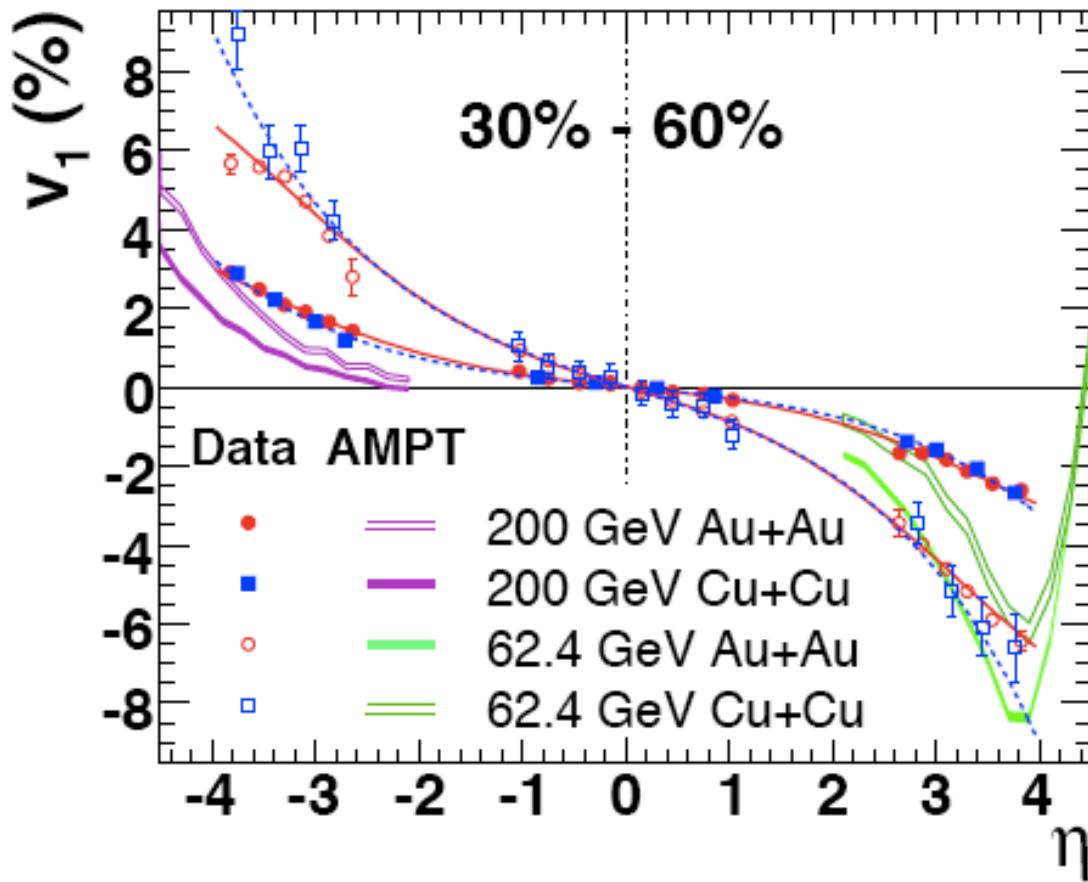
Important for pQCD model calculations

See talks by L. Ruan; Z Xu

Centrality Dependence of Event Anisotropy (v_1, v_2) at RHIC

Directed Flow v_1

STAR: Phys. Rev. Lett. **101** (2008) 252301



- 1) Forward rapidity v_1 : energy dependence, **no N_{part} dependence**
- 2) Model calculations show both beam energy and system size dependence

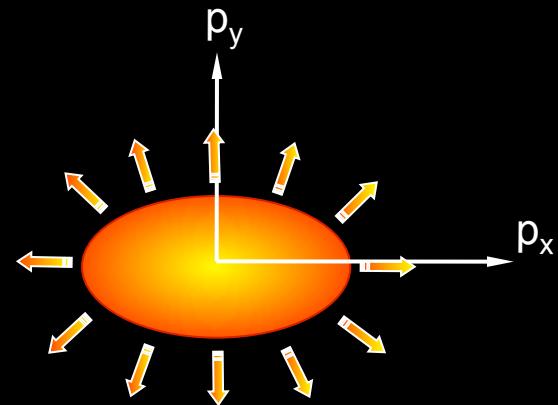
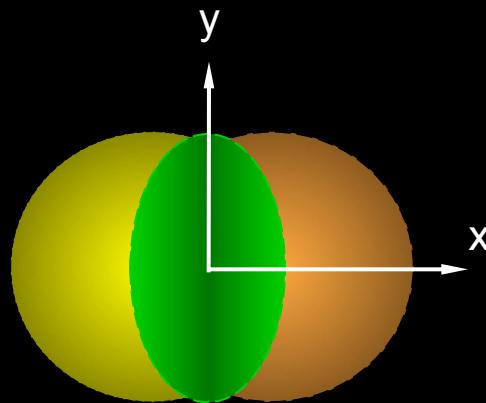
See talk by A. Tang

Anisotropy Parameter v_2

coordinate-space-anisotropy



momentum-space-anisotropy

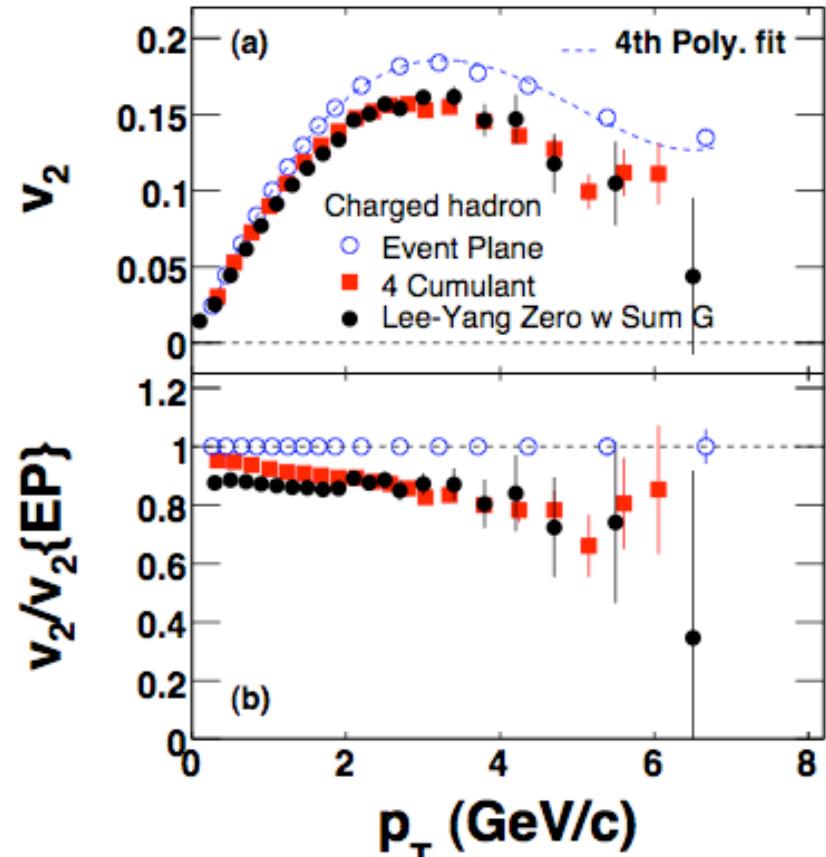
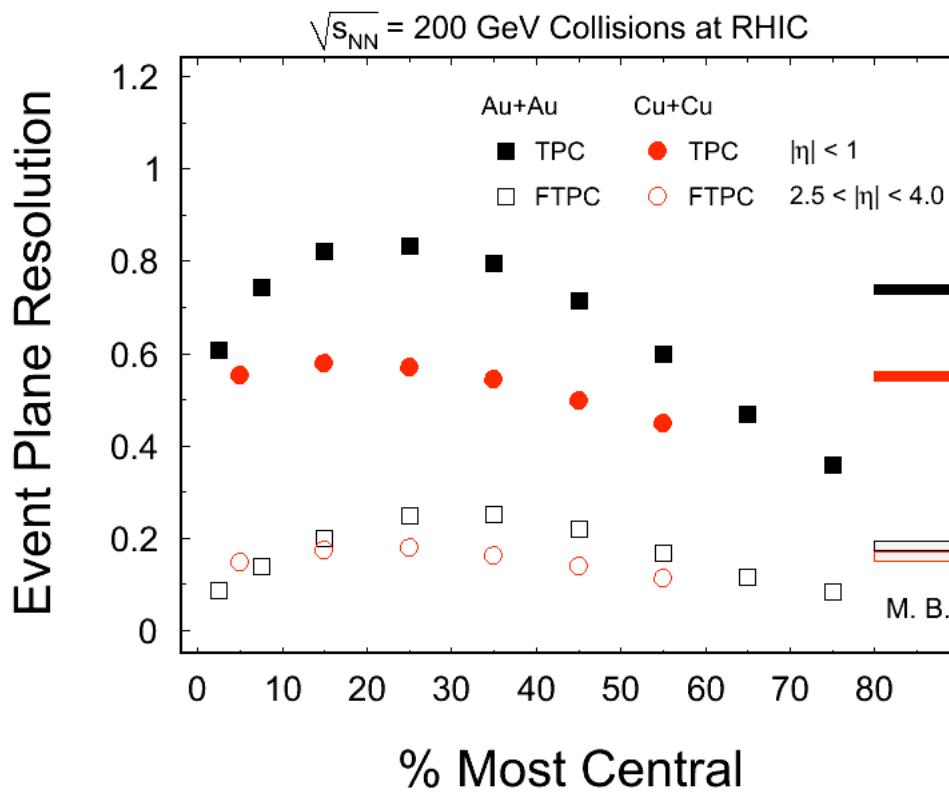


$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

$$v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1} \left(\frac{p_y}{p_x} \right)$$

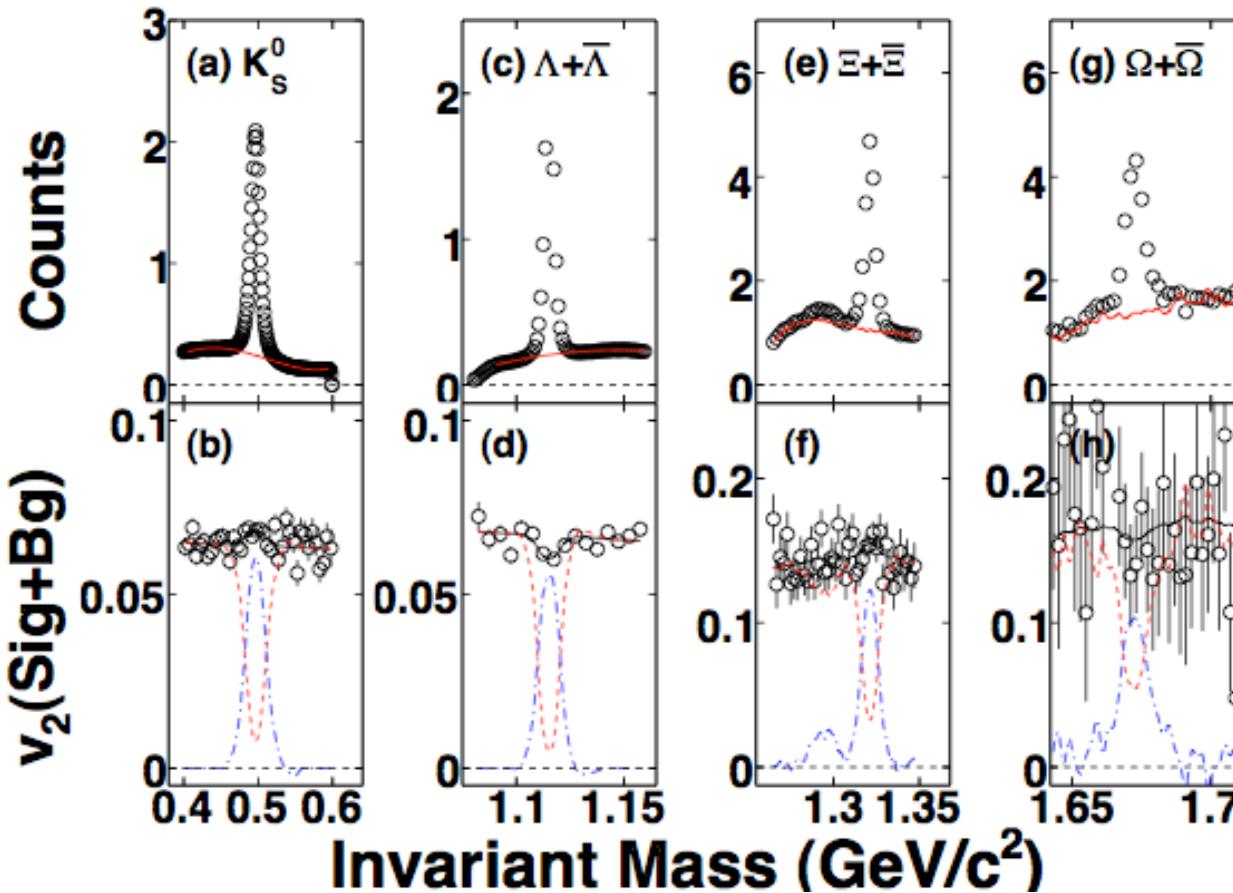
Initial/final conditions, EoS, degrees of freedom

STAR: Phys. Rev. C 77 (2008) 54901



- 1) Large rapidity gap: reduce non-flow contribution
- 2) Non-flow contribution at large p_T region

Particle PID in STAR

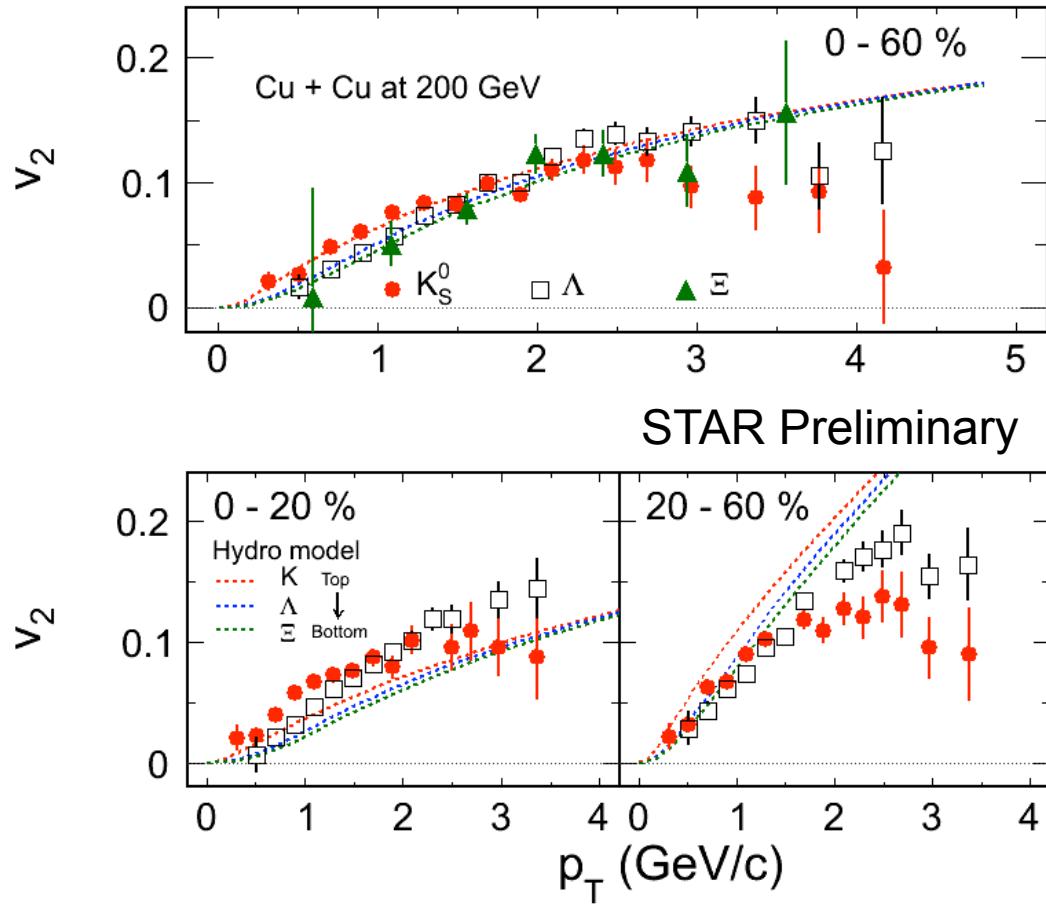


$\pi^\pm, K^\pm, \rho^0, p, \Phi$

Anisotropy v_2 and transverse spectra

200 GeV Au+Au m.b. collisions with ~ 17.5 M events

STAR: Phys. Rev. C77 (2008) 5490



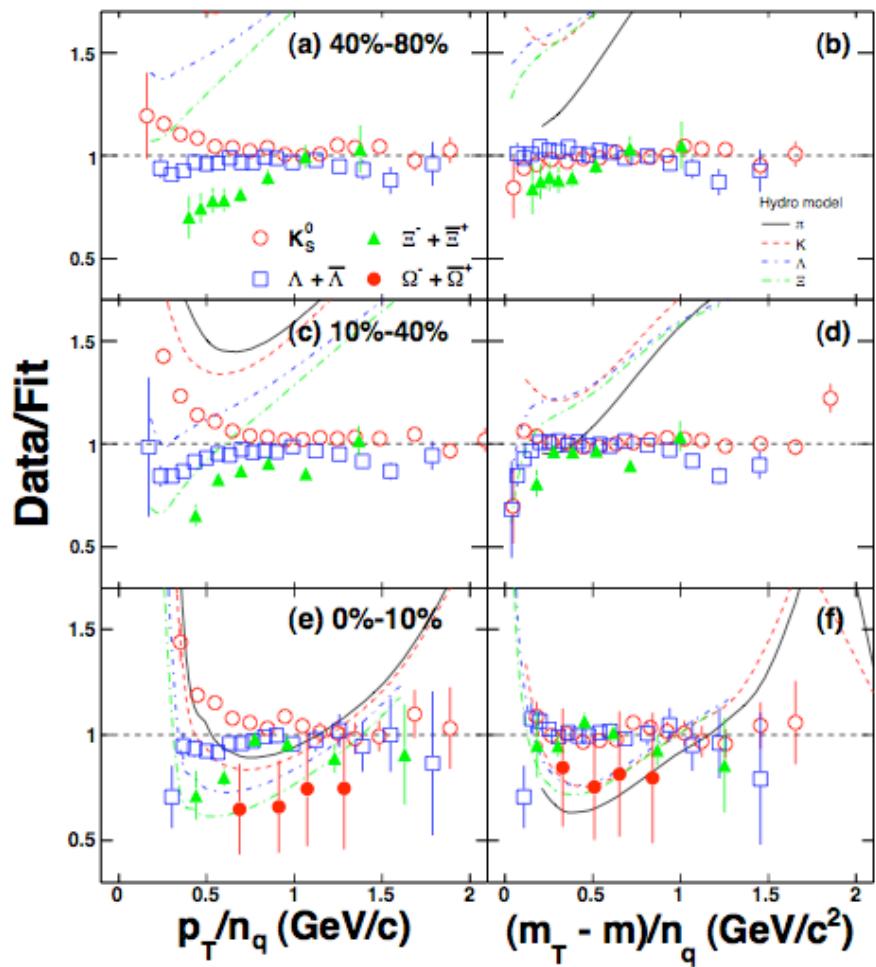
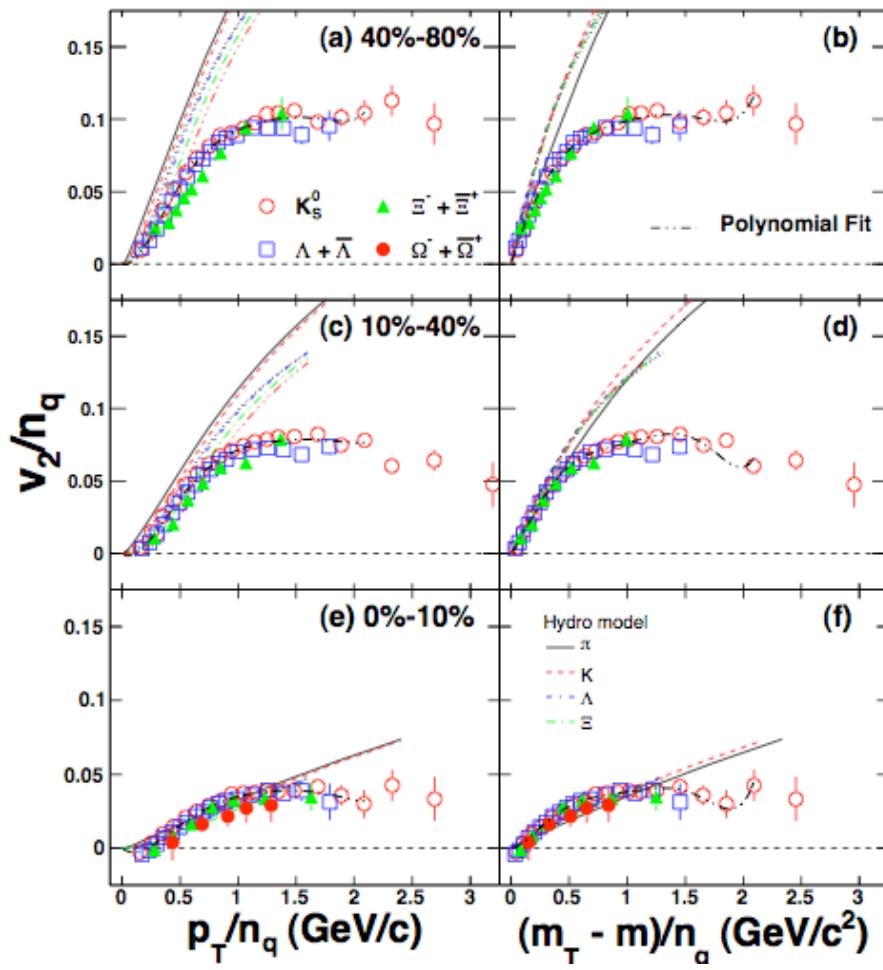
Ideal hydro fails to reproduce the centrality dependence, similar to the case in Au+Au collisions

Fluctuation of v_2 ?

Viscosity?

Incomplete thermalization?

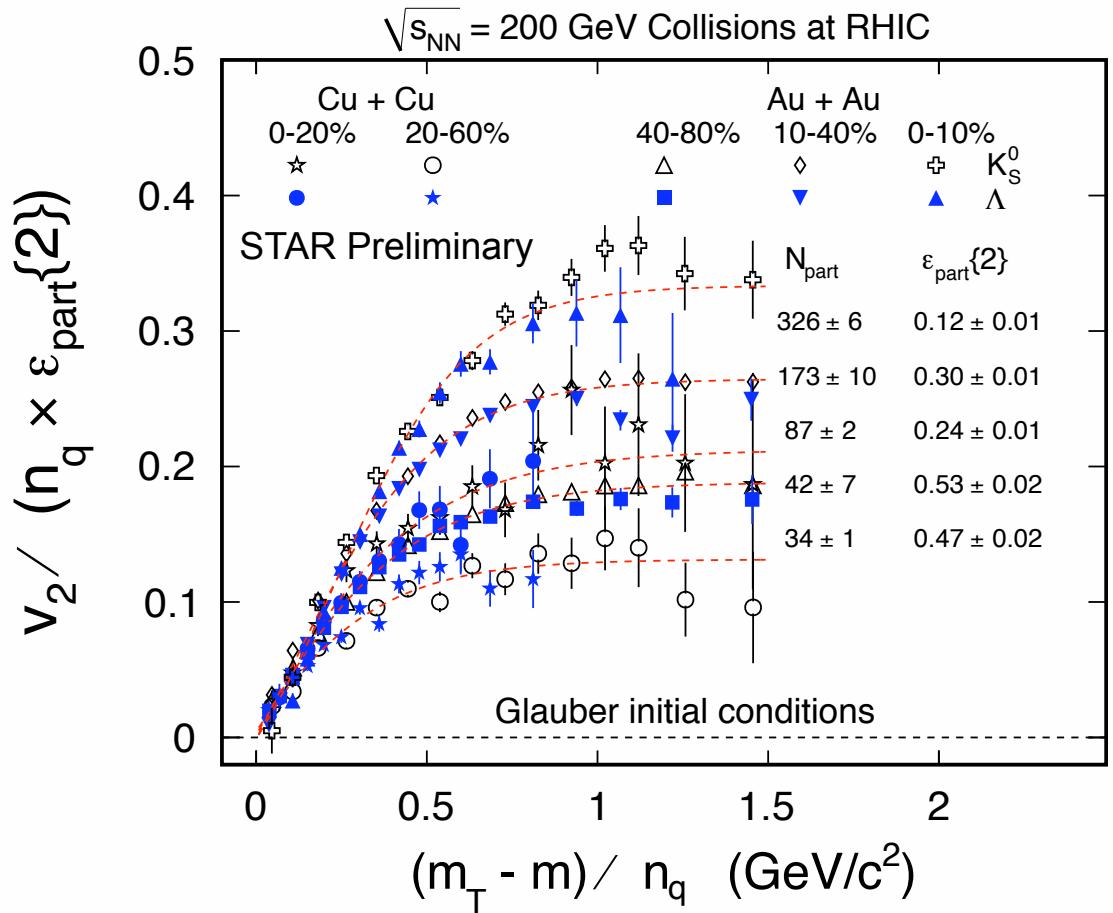
Au+Au - Centrality Dependence



STAR: Phys. Rev. C77 (2008) 54901

⇒ No scaling at low p_T region!
Ideal hydro results do not scale!!!

System Size Driven Collectivity

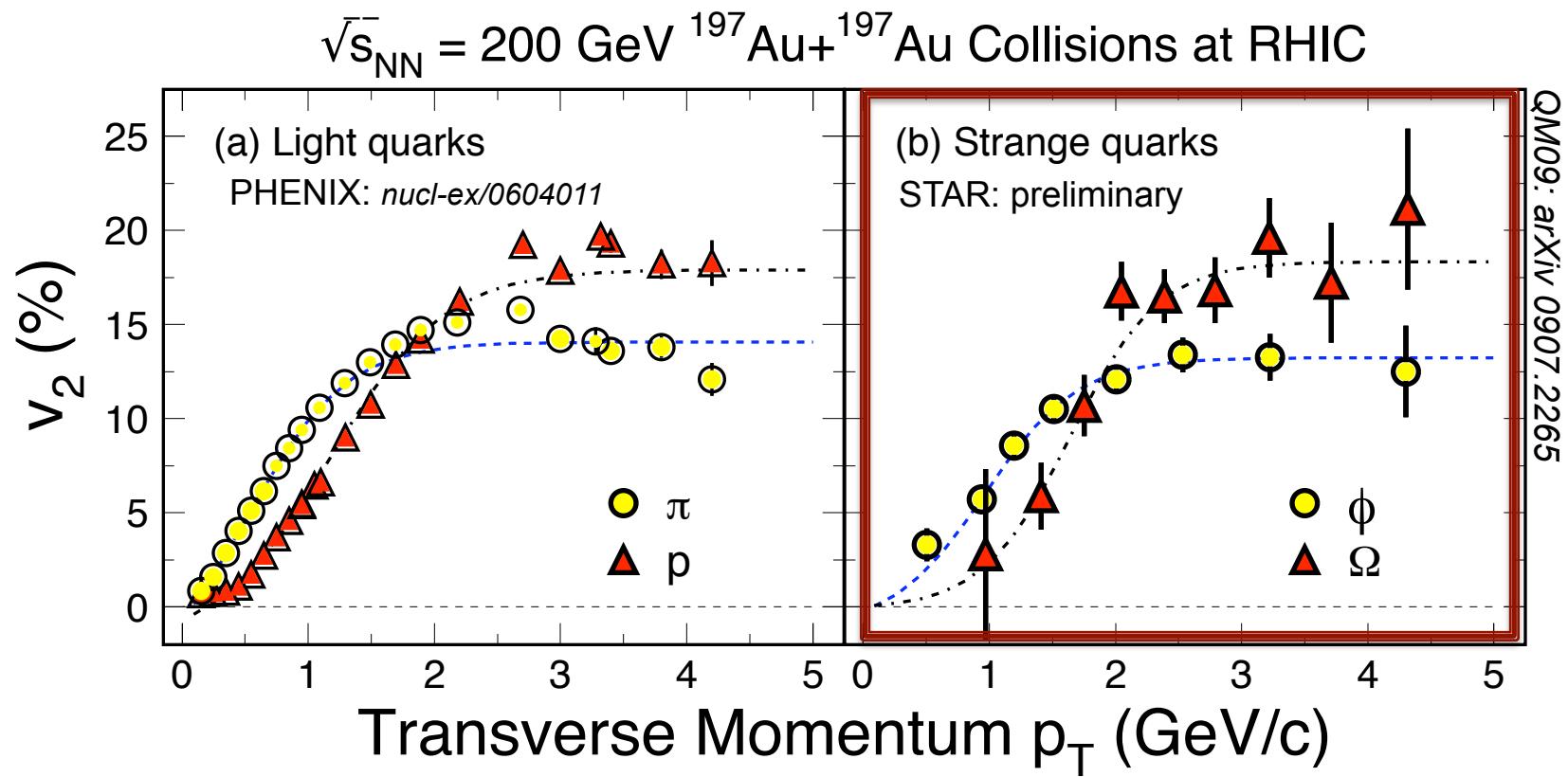


PHENIX: *PRL* **91**, 182301(03)
STAR: *PRL* **92**, 052302(04),
PRL **95**, 122301(05)
PRC **77** (2008) 54901

S. Voloshin, *NPA* **715**, 379(03)
Greco et al, *PRC* **68**, 034904(03)
R.J. Fries, et al. *PRL* **94**:122301(05)
Nonaka et al. *PLB* **583**, 73(04)
X. Dong, et al., *PLB* **597**, 328(04).

Collectivity: Driven by number of participants,
NOT by eccentricity.
Caution: Local equilibrium and perfect fluid

Partonic Collectivity at RHIC



Low p_T ($\leq 2 \text{ GeV/c}$): hydrodynamic mass ordering

High p_T ($> 2 \text{ GeV/c}$): number of quarks ordering

s-quark hadron: smaller interaction strength in hadronic medium

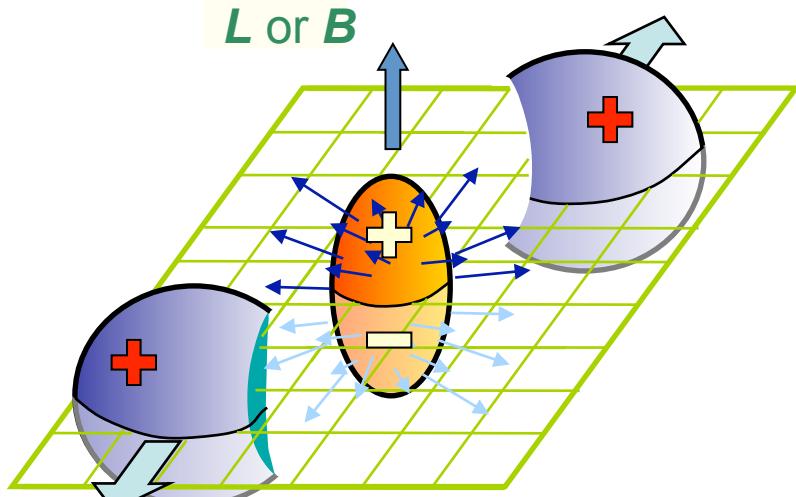
light- and s-quark hadrons: similar v_2 pattern

=> Collectivity developed at partonic stage!

Local Parity Violation in High-Energy Heavy Ion Collisions

Search for Local Parity Violation

in High Energy Nuclear Collisions

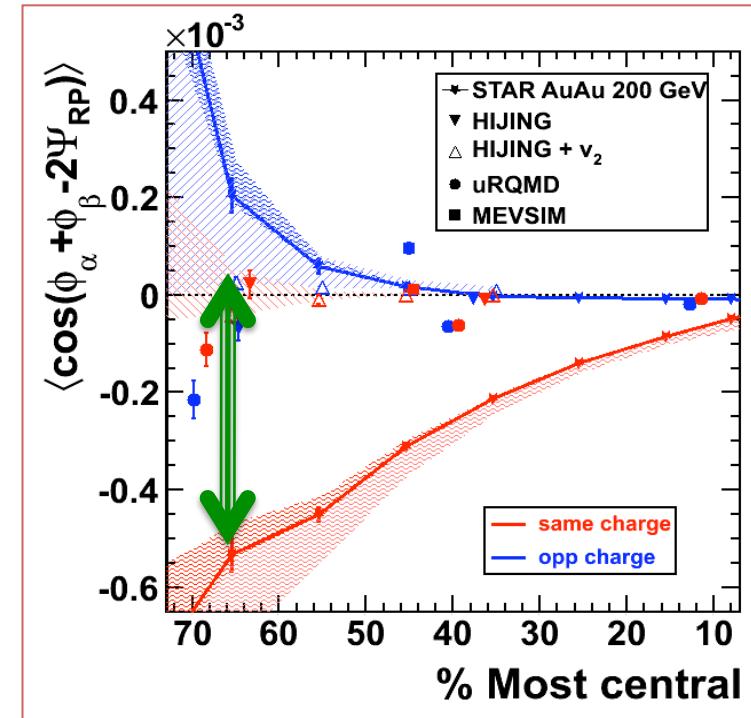


The separation between the same-charge and opposite-charge correlations.

- Strong external EM field
- De-confinement and Chiral symmetry restoration

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$$

Parity even observable
Voloshin, PR C62, 044901(00).
STAR; PRL 103, 251601(09); 0909.1717 (PRC).

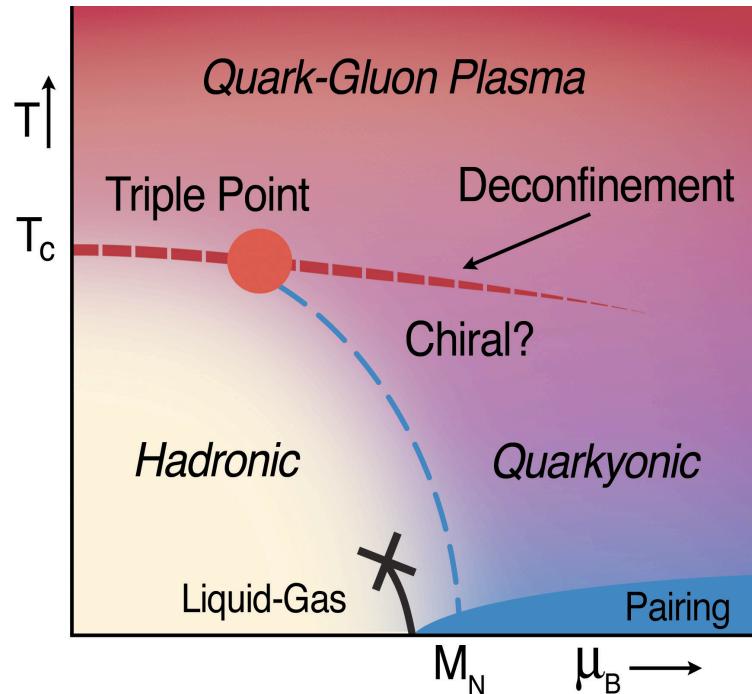
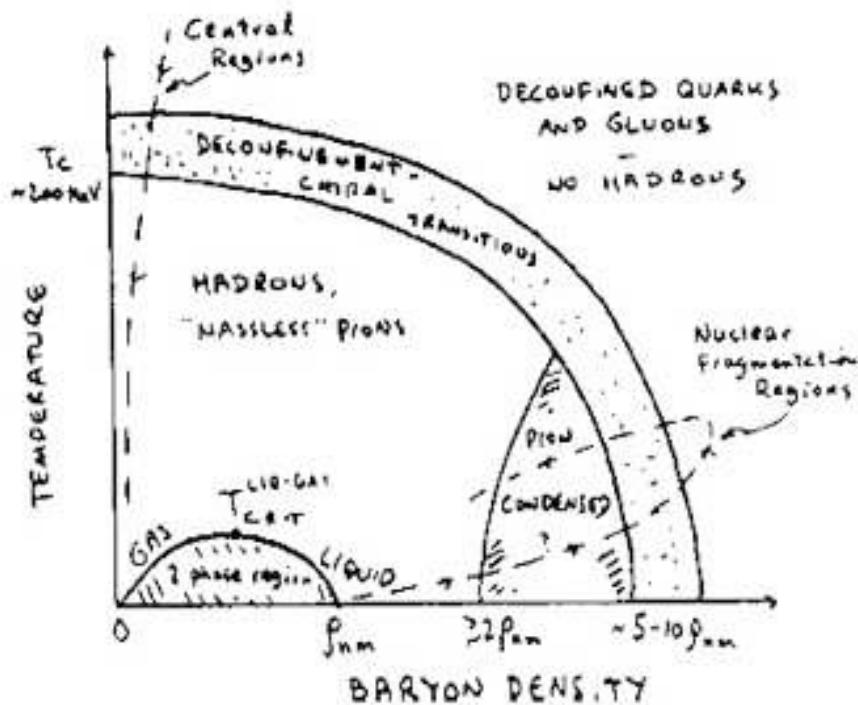


See talk by I. Selyuzhenkov

QCD Phase Diagram RHIC Beam Energy Scan

QCD Phase Diagram

1983 US Long Range Plan - by Gordon Baym



STAR:

- (1) Net-p Kurtosis
- (2) PID hadron v_2 NQ scaling

M. Asakawa, et al. *PRL* **85**:2072(00); *PRL* **101**:122302(08)
 Gavai and Gupta, (03, 05); Gupta 0909.4630, (09)
 M. Cheng et al. 08
 Gupta, Karsch, Stephanov, *INT*, 08

[nucl-th: 0907.4489, NPA830,709\(09\)](#)
 L. McLerran

[nucl-th 0911.4806:](#)

A. Andronic, D. Blaschke, P. Braun-Munzinger,
 J. Cleymans, K. Fukushima, L.D. McLerran,
 H. Oeschler, R.D. Pisarski, K. Redlich, C. Sasaki,
 H. Satz, and J. Stache

STAR Detectors: Full 2π particle identification!

Full MRPC TOF ready for Run10!

TPC

TOF

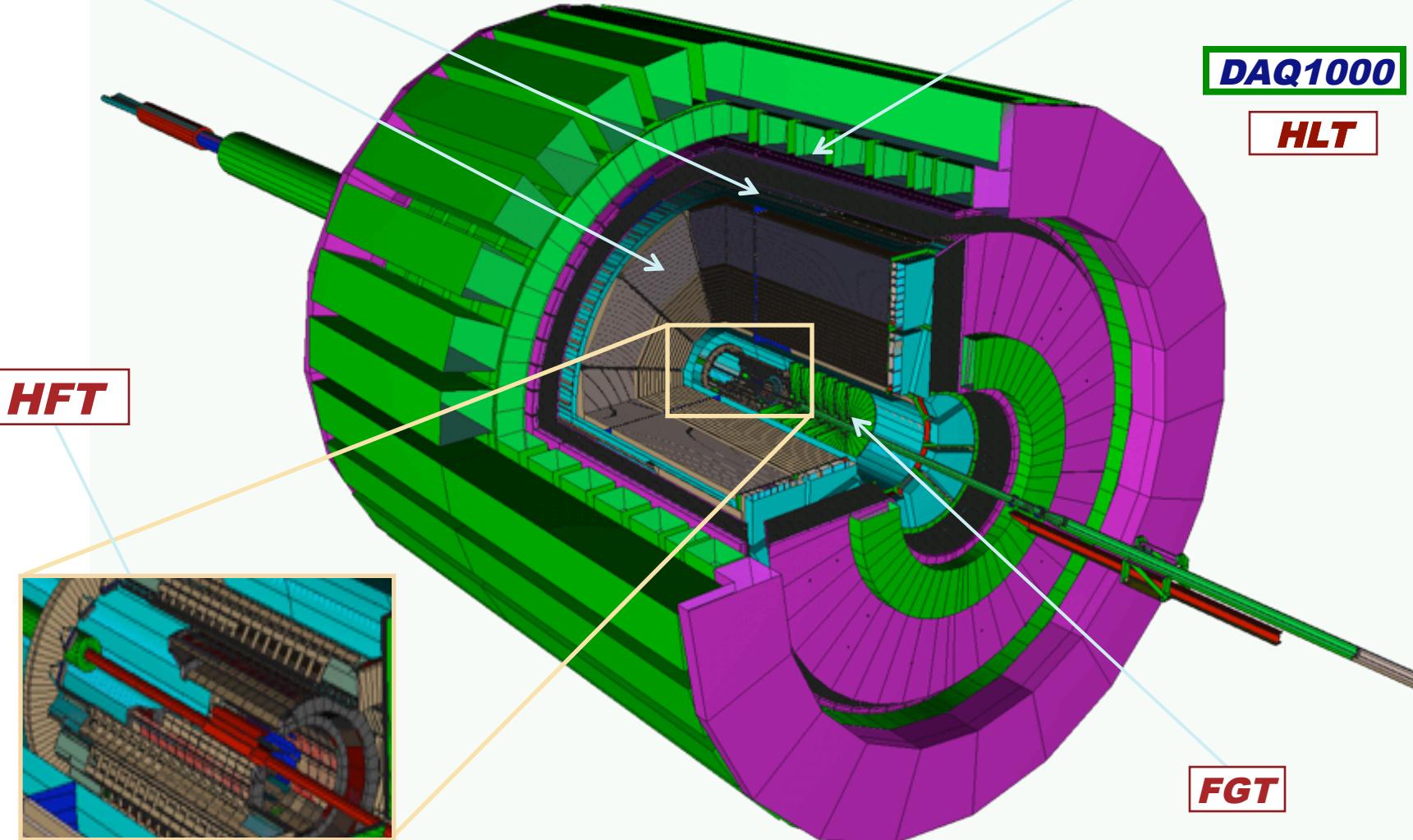
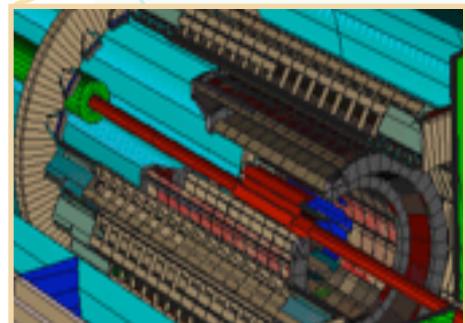
EMC+EEMC+FMS
 $(-1 \leq \eta \leq 4)$

DAQ1000

HLT

HFT

FGT





What is needed to make progress:

1) Theoretical guidance for understanding

Initial conditions
including CGC,
eccentricity ϵ and
energy loss R_{AA}



Non-ideal EOS
including $\eta(\tau, T)$,
 $\zeta(\tau, T)$, ... and
finite size effects



v_1, v_2 , spectra,
HBT, ridge ... as a
function of
(ID, p_T, y, b, \sqrt{s})

Critical point, phase boundary, LPV, ... within dynamic models

Non-equilibrium effects?

2) Systematic and precision measurements

- All ID hadrons including heavy quark vs. (p_T, y, b, \sqrt{s})
- Di-lepton, $1 < \text{mass}_{\text{inv}} < 3 \text{ GeV}$, for purer partonic effect

3) Continue to have the joint meetings